2. Development of Conceptual Models of the Crystal River and West Sopris Creek (CRWS) Study Area

The development of the conceptual model of the hydrogeology followed the watershed-based, hierarchical analysis described by Kolm and Langer (2001) and codified in ASTM D5979 Standard guide for Conceptualization and Characterization of Ground Water Systems. The conceptual model covers, in a qualitative manner, elements of climate, topography, soils and geomorphology, vegetation distribution, surface water characteristics, hydrogeologic framework, hydrology, and anthropogenic activity as related to the ground water system in the study area.

2.1 Climate

The climate in the study area has both local and regional components and includes effects of elevation and slope aspect (i.e., steepness and orientation with respect to the prevailing winds and sunshine). The presence of nearby ridges and ranges may further influence the climate at the lower elevations, causing local rain and sun shadows. There are two relevant weather stations of the National Weather Service (NWS) Cooperative Network in or near the study area: 1) Basalt (station 05014), specifically of interest for the northeast section of the study area including the West Sopris Creek watershed and the lower Crystal River area near Carbondale; and 2) Redstone 4W (station 056970), relevant for the Upper and Central Crystal River area and the area west of the Crystal River. Figures 3 and 4 summarize the average total monthly precipitation (i.e., rain and snowfall SWE - Snow Water Equivalent), snowfall (i.e., thickness of freshly fallen snow), and snow depth (i.e., snow pack) for Basalt and Redstone, Colorado.

![Figure 3. Average Total Monthly Precipitation and Snow Depth for Basalt, Colorado for Period 7/1/1965 – 5/31/1972.](source: Western Regional Climate Center, Desert Research Institute, Reno, Nevada).
Figure 4. Average Total Monthly Precipitation and Snow Depth for Redstone, Colorado for Period 6/1/1979 – 6/30/1994. (source: Western Regional Climate Center, Desert Research Institute, Reno, Nevada).

Figure 5 shows a comparison between the average total monthly precipitation at the Basalt and Redstone stations. Detailed climate data can be found in Appendix 1. Note that the average annual precipitation at Redstone is more than twice that at Basalt, and that the average annual snowfall at Redstone is almost three times that at Basalt. These data provide estimates for the actual precipitation and snowfall in the study area and were used by the Natural Resources Conservation Service to prepare a map of spatially distributed precipitation corrected for elevation (see Figure 6; NRCS, 2005).

Figure 5. Comparison between the Average Total Monthly Precipitation at the Basalt and Redstone stations for the Period 1/1/1971 – 12/31/2000. (source: Western Regional Climate Center, Desert Research Institute, Reno, Nevada).
2.2 Topography and Geomorphology

The surface elevation in the CRWS area ranges from 1900m (6235ft) to 3860m (12660ft) (Figure 7). The topography of the CRWS area has three distinct terrains: 1) well-dissected uplands and hill-slope terrains; 2) connected and disconnected, continuous and discontinuous terraces and landslides; and 3) well-dissected valley bottoms. The well-dissected uplands indicate that surface water and shallow ground water systems will be localized by topography (subregional system). However, the deeper ground water systems, if not topographically dissected by the surficial processes, will be continuous and regional in nature. Examples of these regional systems are observed in western Pitkin County, such as the Green River, Wasatch, and Mesa Verde formation aquifers associated with the Piceance basin, in much of central Pitkin County, such as the Leadville limestone aquifer, and in the Carbondale collapse area, such as the Tertiary sandstone in the northern Crystal River area. The glacial and alluvial terraces, by comparison, are often topographically isolated representing discrete, localized ground water systems. The topographic gradients in the CRWS study area can be divided into two types (Kolm and Gillson, 2004): steep gradient hill slopes (greater than 2% slope); and 2) low gradient valley bottoms and terrace levels (see Figure 8). The topographic gradient is useful in estimating
Figure 7. Topography and Surface Water in Western Pitkin County, Colorado.  
(source: Pitkin County GIS Department, 2007).

water table surfaces, and estimating the amounts of infiltration versus overland flow and interflow.

Slope aspect of steeper hill sides controls local microclimate and, therefore, the distribution of precipitation, snowmelt, and evapotranspiration. This, in turn, influences the redistribution of available water in time and space between overland flow/interflow and ground water recharge (Kolm and Gillson, 2004). Typically, the south and west facing hill slopes are hotter and drier than the north and east facing slopes. These south and west facing slopes will have less winter moisture and snow pack available for the hydrologic system during the spring melt and will have higher evapotranspiration during the growing season. In addition, winter winds are typically westerly, redistributing snow pack to the east facing slopes. Figure 9 shows the south and west facing slopes in the study area.

2.3 Surface Water Characteristics

The study area contains two distinct watersheds (Figure 1): 1) Crystal River watershed, covering most of the study area, including Thompson Creek, Prince Creek, Avalanche Creek and Coal Creek (see Figures 10 and 11); and 2) West Sopris Creek watershed,
Figure 8. Map Showing Steep Gradient Slopes and Low Gradient Valley Bottoms and Terrace Levels in Study Area.

Figure 9. Map Showing Slope Aspect in Study Area.
covering the northeastern corner of the study area. The Crystal River discharges into the Roaring Fork River near Carbondale in Garfield County; West Sopris Creek joins East Sopris Creek at the east end of the study area and discharges as Sopris Creek in the Roaring Fork River just north of the Pitkin County line. A small section in the north-central part of the study area drains directly into the Roaring Fork River. Streams can be gaining (from ground water) or loosing (to ground water), dependent on local hydrology and time of year. The study area also contains various ponds (primarily related to beaver activity, landslides, or to ranchland modifications), and local networks of irrigation and water diversion ditches. Some ditches carry water, at least during part of the year. Springs, seeps, and most wetlands are indicators of ground water discharge to the land surface. The irrigation ditches located on the terraces often have phreatophytes and seeps, indicative of leaky, unlined ditch perimeters. Non-bottomland ditches can transport water over long distances from the diversion points. There are no ditches providing trans-watershed boundary transport of water in the study area.

2.4 Hydrogeologic Framework

The study area is located on the boundary of two major physiographic provinces (Topper and Others, 2003): 1) Southern Rocky Mountains; and 2) Colorado Plateau. The Southern Rocky Mountains in this area are characterized by Laramide mountain ranges and localized Tertiary intrusions (e.g., Elk Mountains, Sawatch Range, Mount Sopris), intersected by stream valleys (e.g., Roaring Fork, Crystal), while the eastern part of the Colorado Plateau is characterized by structural basins and valleys (e.g., Piceance Basin, Eagle Basin) surrounded by Laramide uplifts.
The study area straddles the eastern edge of the Piceance Basin including a section of the Grand Hogback, and covers the westernmost section of the Sawatch uplift and Elk Range Thrust, and the southernmost section of the Carbondale Collapse (Topper and Others, 2003; see Figure 12).

The hydrogeology of the study area consists of two distinct systems covering: 1) the Crystal River watershed; and 2) the West Sopris Creek watershed (see Figure 1). The hydrogeological system present in the Crystal River watershed is complex and quite different form the one in the West Sopris Creek area, which has many of the elements encountered in previous studies (Kolm and Van der Heijde, 2006; Kolm and Others, 2007).

2.4.1 Crystal River Study Area

The hydrogeologic framework of the Crystal River study area hydrological system has multiple distinct hydrogeologic units, including multiple bedrock units, and unconsolidated units consisting of various Tertiary- and Quaternary-aged deposits (Figure 13; Table 1) (Bryant and Martin, 1988; Freethey and Cordy, 1991; Geldon, 2003a, 2003b; Olander and Others, 1974; Streufert and Others, 1998; Streufert, 1999; and Tweto and Others, 1978). The Mt. Sopris Granodiorite, Green River and Wasatch, Mesa Verde sandstones and coals, Mancos sandstones
and Ft Hays carbonates, Dakota/Burro Canyon sandstones, Lower Morrison/Entrada sandstones, Maroon and Minturn sandstones and conglomerates, and Eagle Valley sandstones are unconfined bedrock systems near their recharge areas, and confined bedrock systems at depth. The various shale layers of the Green River, Wasatch, Mesa Verde, Mancos, Upper Morrison, Maroon, Minturn, and Eagle...
<table>
<thead>
<tr>
<th>GIS - Layer</th>
<th>Unit Symbol (CRWS study)</th>
<th>Hydrogeological Unit</th>
<th>Composition</th>
<th>Hydrogeological Characteristic</th>
<th>Basalt Quadrangle Geologic Units</th>
<th>Mt Sopris Quadrangle Geologic Units</th>
<th>Roaring Fork and Crystal Valleys Environmental and Engineering Geology Study</th>
<th>Leadville 1° x 2° Quadrangle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Qal</td>
<td>Quaternary Alluvium</td>
<td>Poorly sorted sands and gravels, clast supported</td>
<td>Potentially good local aquifer; matrix-based permeability, variable thickness</td>
<td>Stream channel, floodplain and low terrace deposits (Qa), Artificial fill (human) (af), Alluvium and colluvium (Qac, Qaco)</td>
<td>Stream channel, floodplain and low terrace deposits (Qa), Artificial fill (human) (af), Alluvium and colluvium (Qac, Qaco)</td>
<td>Younger Alluvial Deposits (Qy)</td>
<td>Alluvium (Qa), Eolian (Qe)</td>
</tr>
<tr>
<td>2</td>
<td>Qgf</td>
<td>Quaternary/Tertiary Gravels, Fans &amp; Terraces</td>
<td>Poorly sorted sands and gravels, clast supported, forms terraces above current river level</td>
<td>Potentially good local aquifer; matrix-based permeability, variable thickness</td>
<td>Terrace Alluvium (Qy), Qtm,Qto), Terrace Alluvium of Capitol Creek (Q11,Q12,Q13), Pleistocene Gravel (Qg)</td>
<td>Terrace Alluvium (Qy), Qtm,Qto,Qt1), Terrace Alluvium of Thompson Creek (Qgt1,Qgt2), High-level gravel (Qg), Gravel of Nettle Creek (Qgn)</td>
<td>Older Alluvial Deposits (Qo)</td>
<td>High level alluvium (Qta), Gravels (Qg, Qgo)</td>
</tr>
<tr>
<td>3</td>
<td>Qm</td>
<td>Quaternary Glacial Deposits (Moraines, Rock Glaciers and Till)</td>
<td>Heterogenous, poorly sorted deposits of boulders, gravel, sand, silt and clay</td>
<td>Potentially good local aquifer, matrix-based permeability, variable thickness</td>
<td>Till (Qti)</td>
<td>Felsenmeer (Qf), Rock Glacier (Qrg1,Qrg2), Till (Qti)</td>
<td>Glacial drift (Qd, Qdo)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Qis</td>
<td>Quaternary colluvial, landslide, hillslope, sheetwash and debris flow deposits</td>
<td>Gravels and rock debris with mixed matrix composition (sand-clay) on valley sides, valley floors and hillslopes, deposited by gravitational processes</td>
<td>Potentially good, highly localized aquifer, matrix-based permeability, variable thickness</td>
<td>Landslide deposits (Qlsr, Qls), Colluvium (Qc, Qco), Talus (Qti), Debris flow (Qdfy, Qdfm, Qdf0), Sheetwash (Qcs)</td>
<td>Sheetwash Deposits (Qsw), Colluvium (Qc, Qco), (Qcs), Talus (Qti), Landslide Deposits (Qls), Debris flow deposits (Qdfy, Qdfm, Qdf0)</td>
<td>Colluvial Deposits (Qc)</td>
<td>Talus (Qti), Landslide (Ql)</td>
</tr>
<tr>
<td>5</td>
<td>Tbaf</td>
<td>Basalt (Miocene?) and ash-flow tuffs (Eocene)</td>
<td>Basalt columns, weathered and fractured, and bedded-non welded tuffs</td>
<td>Potentially good local aquifer where fractured and weathered</td>
<td>Basalt (Tb) and Ash-flow tuffs (Taf)</td>
<td>Basalt (Tbb) and Ash-flow tuffs (Taf)</td>
<td>Basalt (Tbb) and Ash-flow tuffs (Taf)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Ts</td>
<td>Sedimentary Deposits (Miocene?)</td>
<td>Weekly indurated to unconsolidated fluvial deposits (pebbles and cobbles in a matrix of silty sand)</td>
<td>Potentially good local or subregional aquifer; matrix-based permeability, variable thickness</td>
<td>Sedimentary deposits (Ts)</td>
<td>Sedimentary deposits (Ts)</td>
<td>Sedimentary deposits (Ts)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Tgs</td>
<td>Mount Sopris Grano</td>
<td>Granodiorite</td>
<td>Locally moderately permeable fractured crystalline aquifer</td>
<td>Granodiorite of Mount Sopris (Tgs)</td>
<td>Granodiorite of Mount Sopris (Tgs)</td>
<td>Igneous Rocks (Ti)</td>
<td>Upper Tertiary Intrusive Rocks (Tui)</td>
</tr>
<tr>
<td>8</td>
<td>Tw</td>
<td>Wasatch (Paleocene) and Ohio Creek Formation</td>
<td>Channel sandstones and overbank siltsand and shales, (conglomerates, sandstones, shales and claystones)</td>
<td>Potentially good aquifer; both matrix- (regional scale) and fracture-based (local scale) permeability</td>
<td>Wasatch Formation (Tw) and Ohio Creek Formation (To)</td>
<td>Wasatch Formation (Tw) and Ohio Creek Formation (To)</td>
<td>Wasatch and Ohio Creek Formations (Two)</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Correlation of Geological and Hydrogeological Units in the CRWS Study Area.
<table>
<thead>
<tr>
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<th>Leadville 1° x 2° Quadrangle</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Kmv</td>
<td>Mesa Verde (Upper Cretaceous)</td>
<td>Interbedded sandstones and siltstones, shales and carbonaceous shales and coals</td>
<td>Potentially good aquifer; both matrix- (regional scale) and fracture-based (local scale) permeability</td>
<td>Mancos Shale (Km, Knu, Kmv); Fort Hays Limestone (Kmv)</td>
<td>Mancos Shale (Km)</td>
<td>Mancos Shale (Km)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Km</td>
<td>Mancos Shale including Fort Hays Limestone (Upper Cretaceous)</td>
<td>Silty to sandy shale with bentonites with minor limestone- and sandstone beds (main Mancos Shale unit) and thick-bedded, coarse-grained limestone (Fort Hays member)</td>
<td>Mostly aquitard; however, locally moderate to poor aquifer in fracture zones or areas with sand lenses; Fort Hays member is a good local or regional fractured-flow aquifer</td>
<td>Dakota Sandstone and Burro Canyon Formations undivided (Kdb)</td>
<td>Dakota Sandstone and Burro Canyon Formation Formation (Kdb)</td>
<td>Dakota Sandstone and Burro Canyon Formation Formation (Kdb)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Kdb</td>
<td>Dakota Sandstone and Burro Canyon Formations (Lower Cretaceous)</td>
<td>Well indurated, medium to coarse grained quartzose sandstone and conglomerate with occasional siltstones</td>
<td>Potentially good aquifer; both matrix- (regional scale) and fracture-based (local scale) permeability</td>
<td>Morrison Formation (Jm), Entrada Sandstone (Jm), (Jme)</td>
<td>Morrison Formation (Jm), Entrada Sandstone (Jm), (Jme)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Jme</td>
<td>Morrison and Entrada Formations (Upper Jurassic)</td>
<td>Poorly indurated, fine grained, well sorted sandstones, siltstones and claystones</td>
<td>Entrada is a very good regional aquifer with matrix permeability. The Morrison shales are confining layers, while the lower Morrison sandstones are aquifers.</td>
<td>Chiricahua Formation (TrC), State Bridge Formation (TrPsb), (TrPcs), (TrPcm)</td>
<td>Chiricahua Formation (TrC), State Bridge Formation (TrPbs), (TrPcs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>TrCSb</td>
<td>Chiricahua and State Bridge Formations</td>
<td>Thin, even-bedded red beds of calcareous siltstone (Chirie)</td>
<td>Aquitard; generally confining layer</td>
<td>Dakota Sandstone and Burro Canyon Formations undivided (Kdb)</td>
<td>Dakota Sandstone and Burro Canyon Formation Formation (Kdb)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>PPmm</td>
<td>Maroon and Minturn Formations</td>
<td>Grayish-red to pale-red arkosic sandstones, silt- and mudstones, conglomerates; interbed of shale and limestone (Minturn)</td>
<td>Poor aquifer on the regional scale where metamorphosed and well cemented; at the local scale fractured aquifers can occur.</td>
<td>Maroon Formation (PPm)</td>
<td>Maroon Formation (PPm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Pe</td>
<td>Eagle Valley Formation and Eagle Valley Evaporite (Middle Pennsylvanian)</td>
<td>Tan, reddish brown to reddish grey siltstone, gypsum and carbonate rocks. Evaporite contains anhydrite, halite, gypsum and light colored mudstone</td>
<td>Generally poor aquifer except where local sinkholes and karst have developed.</td>
<td>Eagle Valley Evaporite (Pev)</td>
<td>Eagle Valley Evaporite (Pev)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 continued. Correlation of Geological and Hydrogeological Units in the CRWS Study Area.
Valley formations, and the Eagle Valley evaporite are mostly confining bedrock layers throughout most of the system. The unconsolidated hydrogeologic units are unconfined aquifers at the subregional scale, and can consist of a variety of aquifers and confining units at the local scale depending on composition (amount of clay, for example). In this study, hydrogeologic units that are considered significant include the saturated, medium- to high- permeability, unconsolidated sediments, and the water-bearing bedrock units with well-connected fracture zones, as well as the low-permeability, confining bedrock units.

Hydrostructures may exist subregionally and locally. Hydrostructures are folds, and fault and fracture zones that are observed or hypothesized to transmit ground water either vertically or laterally along the bedding planes of competent units, and along fault or fracture planes or zones. These structures may serve as aquifers, or may connect multiple aquifers together. An example of a major hydrostructure is the Crystal River Syncline / fault zone, discussed in a forthcoming section of the report. By comparison, the Elk Range Thrust forms a hydrologic barrier between units, as illustrated in the UCR area.

The major saturated hydrogeologic units consist of: 1) Quaternary landslide, hillslope and sheet wash deposits, and colluvium; 2) glacial gravel deposits, terraces and fans; 3) glacial moraines; 4) alluvial deposits; and 5) Tertiary alluvial deposits in the Carbondale Collapse region (Figure 13 and Table 1). In some specific areas, the Mt. Sopris granodiorite, and the sandstones of the Green River, Wasatch, Mesa Verde, Mancos, Dakota/Burro Canyon, Lower Morrison/Entrada, Maroon, and Eagle Valley Formation bedrock units are aquifers. However, these bedrock units are generally not high-volume, saturated hydrogeologic units of importance in most of the Crystal River area. Hence, despite their regional presence as geologic units, these units do not represent a regional ground water subsystem, except on the western border of Pitkin County in the Piceance Basin region (see Figure 11a). Deeper bedrock hydrogeologic units, such as the Leadville Formation, are not considered viable as water sources in this area due to costs of acquisition, and due to such issues as drilling depths to water and low well yields.

2.4.2 West Sopris Creek Study Area

The hydrogeologic framework of the West Sopris Creek study area hydrological system has multiple distinct hydrogeologic units, including bedrock units, and unconsolidated units consisting of various Quaternary deposits (Figure 13; Table 1) (Bryant and Martin, 1988; Freethy and Cordy, 1991; Geldon, 2003a, 2003b; Olander and Others, 1974; Streufert and Others, 1998; Streufert, 1999; and Tweto and Others, 1978). The Dakota/Burro Canyon, Ft. Hays, and Mancos sandstone and limestone aquifers are unconfined systems near their recharge areas, and confined systems at depth. The various shale layers of Mancos Shale and the Lower Bedrock units, consisting of Morrison and older rocks, are confining layers throughout most of the system. The unconsolidated hydrogeologic units are unconfined aquifers at the subregional scale, and can consist of a variety of aquifers and confining units at the local scale depending on composition (amount of clay, for example). In this study, hydrogeologic units that are considered significant include the saturated, medium- to high- permeability, unconsolidated sediments, and the water-bearing bedrock units with well-connected fracture zones, as well as the low-permeability, confining bedrock units.
Hydrostructures may exist subregionally and locally. Hydrostructures are geologic folds, and fault and fracture zones that are observed or hypothesized to transmit ground water either vertically or laterally along dip slopes, or the fault or fracture plane or zone. These hydrostructures may serve as aquifers, or may connect multiple aquifers together. An example of multiple hydrostructures is observed at the northern portion of the West Sopris Creek study area just south of Basalt, Colorado, where multiple faults bring the Dakota sandstones to the surface and near surface, as discussed in a forthcoming section of the report.

The major saturated hydrogeologic units of the West Sopris Creek study area consist of: 1) Quaternary landslide, hillslope and sheet wash deposits, and colluvium; 2) glacial gravel deposits, terraces and fans; 3) glacial moraines; and 4) alluvial deposits (Table 1; Figure 13). In some specific areas, the Upper and Lower Mancos sandstone, Ft. Hays Limestone, Dakota/Burro Canyon, and lower Morrison/Entrada bedrock units are aquifers. However, these bedrock units are generally not high-volume, saturated hydrogeologic units of importance in most of the West Sopris Creek area. Hence, despite their regional presence as geologic units, these units do not represent a regional ground water subsystem (Table 1; Figure 13). Deeper bedrock hydrogeologic units, such as the Maroon, Eagle Valley, or Leadville Formations, are not considered viable as water sources in this area due to costs of acquisition, and due to such issues as drilling depths to water and low well yields.

2.5 Ground Water Flow System

The general conceptual model of the ground water flow system consists of inputs and outputs based on climate (infiltration of precipitation and snowmelt), stream functions (gaining or losing), vegetation (evapotranspiration), topography (steepness, aspect, degree of landscape dissection), geomorphology and soils, and human activity (irrigation ditches and irrigation, urbanization, ISDS, wells), and geology. Based on the hierarchical approach of Kolm and Langer (2001), no regional system has been identified as being important, and subregional and local scale ground water flow systems dominate in the CRWS area (Figure 1).

The broad regional hydrologic system inputs include infiltration of precipitation as rain and snowmelt, areas of losing streams and water bodies (reservoirs, ponds), and upland irrigation areas (irrigation return flow). The hillslope subsystem consists of the hydrologic processes of surface runoff (overland flow) and rapid near surface runoff (interflow or shallow through flow), saturated ground water flow in parts of the bedrock units, landslides, terraces, moraines, and valley bottoms, and discharge to springs and seeps, graining streams, and by plants as evapotranspiration. In general, flow in these systems is towards the valley bottom, perpendicular to the major streams. Where bedrock aquifers intersect hill slopes, local recharge may force the ground water into a more regional pattern determined by geological structure and independent from local topography and hydrography.

The Terrace subsystems, located in close proximity to the valley subsystems, have a unique, sometimes complex ground water story, often resulting from human interference as described in subsequent paragraphs and figures of local conceptual models. Under natural conditions, these subsystems have hydrologic system inputs and outputs, as well as location in
the landscape, similar to hillslope subsystems. However, anthropogenic influences have frequently attached these subsystems hydrologically to adjacent valley bottom subsystems.

The Valley Bottom subsystems, where stream-aquifer-wetland interactions occur, are areas of both ground water recharge and discharge. Here, ground water flow can have a rather diffuse character and often aligns more or less with the streams. These subsystems depend primarily on interactions with the Crystal River and West Sopris Creeks and subsidiary streams. The associated wetlands are predominantly of the slope-type with some riverine-type classifications in the Crystal River system given the ground water support of various bedrock ground water systems, and the high gradient mass wasting / landslide ground water systems observed on the hill slopes of the Crystal River canyon. The associated wetlands are predominantly riverine in the West Sopris Creek system given the lack of supporting regional or subregional ground water bedrock or hill slope systems.

2.6 Conceptual Ground Water System Models

There are five general conceptual models within the regional scale context of the CRWS area: 1) Upper Crystal River (UCR) Subsystem north and south of Redstone, Colorado; 2) Central Crystal River (CCR) Subsystem in the vicinity of the Tertiary intrusions north of Redstone, including Avalanche Creek; 3) Lower Crystal River (LCR) Subsystem north of the Tertiary intrusions, including Prince Creek; 4) West Sopris Creek (WSC) Subsystem including the lower reach of East Sopris Creek and Sopris Creek; and 5) Thompson & Coal Creek (TCC) Subsystem. The location of representative, generalized cross-sections for these conceptual models are shown in Figure 13. The conceptual models are discussed in forthcoming sections.

2.6.1 Upper Crystal River (UCR) Subsystem

There are two significant groups of hydrogeologic units in the UCR area: (1) Quaternary unconsolidated materials, which are predominantly glacial, colluvial, and alluvial deposits, overlying (2) Pre-Quaternary bedrock units, including the sandstones of the Mesa Verde, Dakota/Burro Canyon, Lower Morrison/Entrada, Maroon, and Eagle Valley Formations that may be water-bearing, and the intervening shale and gypsum that may be poorly transmissive confining layers (Figures 13 and 14; Table 1). The Quaternary unconsolidated materials are locally heterogeneous, with predominantly coarser materials in the glacial moraine and landslide deposits, and a mix of coarser and finer materials in the alluvial deposits. The thickness of the sediments ranges from less than 1 ft to greater than 100 ft. Estimates of hydraulic conductivity (K) ranges from 10 to 100 ft per day (Harlan and others, 1989). The shale bedrock units are the dominant confining layers with small hydraulic conductivity values less than .01 ft per day.

Locally, the sandstone units in the Mesa Verde, Mancos, Dakota/Burro Canyon, Lower Morrison/Entrada, Maroon, Minturn, and Eagle Valley Formations may serve as minor aquifers in areas where glacial gravels are not adequate for water supply (Kmv, Km, Kd/Kbc, Jme, and Ppm in Figures 13 and 14 and in Table 1). These sandstone units occur as tilted/dipping sedimentary beds mainly on the hilltops and hillslopes above the Crystal River Valley, and have
Figure 14. Conceptual Model of the Upper Crystal River (UCR) Subsystem.
both matrix and fracture ground water flow. Given the geometry and the complex matrix/fracture flow nature of these hydrogeologic units, these aquifers have variable thicknesses and hydraulic properties based on the geologic materials, geologic structure and respective landscape location. There are some locations where these units are located directly underneath the unconsolidated materials of the Valley, and the unconsolidated and bedrock aquifers may be in direct hydraulic connection (Figure 14). Most wells have not tapped these potential bedrock aquifers in this area.

The Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the slope steepness, slope aspect, and to position in the landscape, and by the incidental leaky irrigation ditch (Figure 14). The unconsolidated units are variably to fully saturated based on spatial location and seasonal precipitation events. There may be lateral and vertical connection between the sandstones of the Mesa Verde, Mancos, Dakota/Burro Canyon, Lower Morrison/Entrada, Maroon, Minturn, and Eagle Valley Formations and the unconsolidated materials in some locations (Figure 14). Bedrock aquifers on the east side of the Crystal River Valley have a westerly dip; therefore, ground water in these units would tend to recharge the overlying unconsolidated materials. Bedrock aquifers on the Valley floor and west side of the Crystal River Valley have a similar westerly dip; therefore, ground water in these units would tend to be recharged by the overlying unconsolidated materials and the Crystal River. Otherwise, the intervening shale does not allow significant lateral or upward/downward movement of ground water from the bedrock aquifers into the unconsolidated materials. The unconsolidated units discharge ground water locally into the Crystal River and tributaries (Figure 14). Therefore, the local ground water flow is from the unconsolidated glacial and colluvial materials into unconsolidated alluvium and, finally, to springs, seeps, or the Crystal River and tributaries. Some of the ground water entering the alluvium may flow parallel to the stream for some distance before discharging to the stream. Additional discharges from the unconsolidated units occur as evapotranspiration and well withdrawal (Figure 14). There may be some reaches of the Crystal River where surface water enters the alluvium to recharge the underlying bedrock system as part of the deep regional recharge zone of the greater Piceance Basin (Figure 14).

The bedrock system in the UCR is complex, and needs to be evaluated on a site location basis. Generally, the sandstones of the Maroon and Eagle Valley Formations are located on the east side of the Crystal River Valley, and dip to the west underneath the Valley floor. These sandstones would be recharged by direct infiltration of precipitation, or by ground water moving through the overlying colluvium and unconsolidated glacial materials. Ground water would flow down dip in these sandstones, and would either discharge into the unconsolidated materials of the Crystal River Valley floor, or could flow up through the Crystal River fault and fracture zone to discharge through the alluvium to the Crystal River. In comparison, the sandstones of the Mesa Verde, Mancos, Dakota/Burro Canyon, and Lower Morrison/Entrada Formations are located mostly on the west side of the Crystal River Valley, and dip to the west away from the Valley floor. These younger sandstones would be recharged by direct infiltration of precipitation, or by ground water moving through the overlying colluvium and unconsolidated glacial materials. Ground water would flow down dip in these sandstones and become regional flow into the deeper zones of the Piceance Basin. Groundwater in the older bedrock units located east of the thrust fault would flow vertically downward into underlying Minturn and Maroon bedrock units and discharge into the Crystal River (Figure 14). Figures 15, 16 and 17
provide a landscape view of the topography, geomorphology and hydrography of the UCR subsystem.

![Google Earth View of the Upper Crystal River (UCR) Subsystem (looking north).](image)

2.6.2 Central Crystal River (CCR) Subsystem

There are two significant groups of hydrogeologic units in the CCR area: (1) Quaternary unconsolidated materials, which are predominantly glacial, colluvial, and alluvial deposits, overlying (2) Pre-Quaternary bedrock units, including a) the sandstones of the Maroon, Minturn, and Eagle Valley Formations that may be water-bearing, and the intervening shale that may be poorly transmissive confining layers and b) Tertiary Mt. Sopris granodiorite (Figures 13 and 18; Table 1). The Quaternary unconsolidated materials are locally heterogeneous, with predominantly coarser materials in the glacial moraine and landslide deposits, and finer materials in the alluvial deposits. The thickness of the sediments ranges from less than 1 ft to greater than 100 ft. Estimates of hydraulic conductivity (K) ranges from 10 to 100 ft per day (Harlan and Others, 1989). The shale bedrock is the dominant underlying confining layer with small hydraulic conductivity values less than .01 ft per day.
The Crystal River defines the axis of the syncline and a regional fault and fracture zone. The bedrock beneath the river will have increased fracture permeability and will be a linear region of high transmissivity and specific yield similar in concept to that of an engineered French drain.

Locally, the sandstone units in the Maroon, Minturn, and Eagle Valley Formations, and the Tertiary Mt. Sopris granodiorite unit may serve as minor aquifers in areas where glacial gravels are not adequate for water supply (Tg, PPM, and Pev in Figure 18 and Table 1). The sandstone units occur as tilted/dipping sedimentary beds mainly on the hilltops and hillslopes above the Crystal River Valley, and have both matrix and fracture flow characteristics. The Tertiary Mt. Sopris granodiorite occurs prominently as intrusive bodies along the valley floor near Mt. Sopris, and has fracture flow characteristics. Given the geometry and the complex matrix and fracture flow nature of these hydrogeologic units, these aquifers have variable thicknesses and hydraulic properties based on the geologic materials, geologic structure and respective landscape location. There are some locations where these units are located directly underneath the unconsolidated materials of the Valley, and the unconsolidated and bedrock aquifers may be in direct hydraulic connection (Figure 18). Most wells have not tapped these potential bedrock aquifers in this area.
The Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the slope steepness, slope aspect, and to position in the landscape, and by the incidental leaky irrigation ditch (Figure 18). The unconsolidated units are variably to fully saturated based on spatial location and seasonal precipitation events. There may be lateral and vertical connection between the sandstones of the Maroon, and Eagle Valley Formations and the Mt. Sopris granodiorite with the unconsolidated materials in some locations (Figure 18). Bedrock aquifers on both sides of the Crystal River Valley dip toward the valley center due to the Crystal River syncline; therefore, ground water in these bedrock units would tend to be recharged by the overlying unconsolidated materials near the hill tops. Conversely, ground water in these bedrock units would tend to discharge into the overlying unconsolidated materials near the valley bottoms. Bedrock aquifers on the Valley floor would be in direct connection with the unconsolidated materials, and would discharge ground water up through the alluvium into the Crystal River. In areas where the underlying bedrock is shale, there will be no significant lateral or upward/downward movement of ground water from the bedrock aquifers into the unconsolidated materials. The unconsolidated units discharge ground water locally into the Crystal River and tributaries (Figure 18). Therefore, the local ground water flow is from the unconsolidated glacial and colluvial materials into unconsolidated alluvium and, finally, to
Figure 18. Conceptual Model of the Central Crystal (CCR) Subsystem.
springs, seeps, or the Crystal River and tributaries. Some of the ground water entering the alluvium may flow parallel to the stream for some distance before discharging to the stream. Additional discharges from the unconsolidated units occur as evapotranspiration and well withdrawal (Figure 18).

The bedrock system in the CCR is complex, and needs to be evaluated on a site location basis. Generally, the sandstones of the Maroon, Minturn, and Eagle Valley Formations and the Tertiary Mt. Sopris granodiorite are located on both sides of the Crystal River Valley, and, given the synclinal structure, the sandstones dip towards the Valley floor (Figure 18). These sandstones and granodiorite would be recharged by direct infiltration of precipitation, or by ground water moving through the overlying colluvium and unconsolidated glacial materials. Ground water would flow with topography in the granodiorite and down dip in the sandstones, and would either discharge into the unconsolidated materials of the Crystal River Valley floor, or could flow up through the Crystal River fault and fracture zone to discharge through the alluvium to the Crystal River. In comparison, in areas where shale of the Eagle Valley Fm. or evaporate underlie the unconsolidated materials, ground water in the bedrock aquifers under the valley floor would flow parallel to the Crystal River until direct connection between bedrock aquifer and unconsolidated material was established, as observed near the mouth of the Crystal River Canyon. Some deep bedrock aquifer connections with the surface are observed in places like Penny Hot Springs. Figures 19 and 20 provide a landscape view of the topography, geomorphology and hydrography of the CCR subsystem.

![Google Earth View of the Central Crystal River (CCR) Subsystem (looking north).](image-url)
2.6.3 Lower Crystal River (LCR) Subsystem

There are two significant groups of hydrogeologic units in the LCR area: (1) Quaternary unconsolidated materials, which are predominantly glacial moraine and landslide deposits, glacial and alluvial terraces or modern alluvial deposits, overlying (2) Pre-Quaternary bedrock units, including a) the sandstones of the Mancos, Dakota/Burro Canyon, Lower Morrison/Entrada, Maroon, Minturn, and Eagle Valley Formations that may be water-bearing, and the intervening shale that may be poorly transmissive confining layers (Table 1, Figures 13 and 21a,b) and b) Tertiary sandstones and alluvial deposits of the Carbondale Collapse (Figures 12b and 21b). The Quaternary unconsolidated materials are locally heterogeneous, with predominantly coarser materials in the glacial moraine and landslide deposits and glacial and alluvial terraces, and finer materials in the modern alluvial deposits. The thickness of the sediments ranges from less than 1 ft to greater than 100 ft. Estimates of hydraulic conductivity (K) ranges from 10 to 100 ft per day (Harlan and Others, 1989). Both fractured sandstone and shale bedrock is the underlying hydrologic unit with variable hydraulic conductivity values in the upper part of the LCR, whereas the Tertiary sandstones associated with the Carbondale Collapse is the dominant underlying aquifer with potentially large hydraulic conductivity values of greater than 1 ft per day.
The Tertiary sandstones and alluvium of the Carbondale Collapse (Ts) may serve as a significant aquifer in the LCR area (Table 1; Figures 13, and 21a,b). This alluvial unit occurs as gently dipping sedimentary beds mainly underneath the terraces and unconsolidated deposits of the Crystal River Valley, and has matrix ground water flow characteristics. Given the geometry of the Carbondale Collapse, the Tertiary alluvium is thinnest at the southern, western, and eastern ends of the Carbondale Collapse area located in the southern part of the LCR area; the Tertiary alluvium thickens to the north towards Carbondale (Figure 21a,b). This hydrogeologic unit will have complex matrix flow due to the variable hydraulic properties based on the geologic materials and respective landscape location. The Tertiary alluvium is located directly underneath the Quaternary hydrogeologic units of the LCR area; therefore, these units will be in direct hydraulic connection (Figures 21a,b). Most wells have not tapped the Tertiary alluvial aquifer in this area.
Locally, the sandstone and limestone units in the Mancos, Dakota/Burro Canyon, Lower Morrison/Entrada, Maroon, Minturn, and Eagle Valley Formations may serve as minor aquifers in areas where glacial gravels are not adequate for water supply (Kms, Kdb, Jme, PPm, and Pe in Table 1; Figures 13 and 21a,b). The sandstone units occur as tilted/dipping sedimentary beds mainly underneath the terraces and unconsolidated deposits of the Crystal River Valley, and have both matrix and fracture flow characteristics. Given the geometry and the complex matrix and fracture flow nature of these hydrogeologic units, these aquifers have variable thicknesses and hydraulic properties based on the geologic materials, geologic structure and respective landscape location. There are some locations where these units are located directly underneath the Quaternary unconsolidated materials and Tertiary sandstones of the Valley, and are in direct
hydraulic connection (Figure 21a,b). Most wells have not tapped these potential bedrock aquifers in this area.

The Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the location of open areas and position in the landscape. Locally, ditches located on each terrace are influent (losing) and, together with irrigation return flow, recharges the unconsolidated units (Figure 21a,b). The Quaternary unconsolidated units are variably to fully saturated based on spatial location (geographically and proximity to irrigation ditches and irrigated areas) and seasonal precipitation events. Ground water in the unconsolidated units laterally recharges the unconsolidated units located topographically below by the interflow and overland flow processes. Likewise, the lowest terraces recharge the modern alluvium by interflow and overland flow (Figure 21a,b). Ground water in the Quaternary unconsolidated units discharges locally into streams that cut through the terraces, and from the alluvium into the Crystal River and tributaries (Figure 21a,b). Other sources of discharge from the Quaternary unconsolidated units include phreatophytes (evapotranspiration) and well withdrawals. Therefore, the local ground water flow is from the unconsolidated glacial and alluvial terrace materials into the Quaternary unconsolidated alluvium and, finally, to phreatophytes, springs, seeps, or the Crystal River and tributaries. Some of the ground water entering the Quaternary alluvium may flow parallel to the stream for some distance before discharging to the stream, or may flow vertically downward into the Tertiary alluvial system near the edge of the Carbondale Collapse at the southern end of the LCR area (Figure 21a,b). In addition, ground water may flow vertically upward from the Tertiary alluvial systems into the Quaternary alluvium to be discharged into the Crystal River near the center of the Carbondale Collapse near Carbondale, Colorado (outside Pitkin County).

The Tertiary alluvial system (Ts) in the LCR is complex, and needs to be evaluated on a site location basis. Generally, the Tertiary alluvium is located underneath the Quaternary unconsolidated materials in the area of the Carbondale Collapse and, given the basin-like nature of the collapse structure, the alluvium increases in thickness and dips towards Carbondale, Colorado, the center of the feature (Figures 12b, 13 and 21a,b). The Tertiary alluvium is recharged by direct infiltration of precipitation, or by ground water moving through the overlying Quaternary colluvium, glacial and alluvial terraces, and modern alluvium (Figure 21a,b). Ground water would flow in the Tertiary alluvium with the regional dip toward the center of the Carbondale Collapse area, and would discharge through the Quaternary unconsolidated materials to the Crystal River and tributaries.

The bedrock system in the LCR area is complex, and needs to be evaluated on a site location basis. The Quaternary unconsolidated materials may have lateral and vertical connection with the sandstones of the Mancos, Dakota/Burro Canyon, Lower Morrison/Entrada, Maroon, Minturn, and Eagle Valley Formations in some locations (Figure 21a,b). Ground water in these bedrock units would tend to be recharged by the overlying unconsolidated materials. Bedrock aquifers on the west side of the Crystal River Valley dip away from the valley center due to the regional structures. Ground water in these bedrock units would tend to flow into the regional system, not into the overlying Quaternary unconsolidated materials or Tertiary alluvium. In areas where the underlying bedrock is shale, there will be no significant lateral or upward/downward movement of ground water from the bedrock aquifers into the Quaternary
unconsolidated materials or Tertiary alluvium. Figures 22, 23, 24 and 25 provide a landscape view of the topography, geomorphology and hydrography of the LCR subsystem.

Figure 22. Google Earth View of the Lower Crystal River (LCR) Subsystem (looking north to Carbondale, Colorado).

Figure 23. Photograph of the Lower Crystal River (LCR) Subsystem (panoramic view near Potato Bill Creek).
2.6.4 West Sopris Creek (WSC) Subsystem

The WSC subsystem covers the West Sopris Creek watershed, the lower reach of East Sopris Creek, and Sopris Creek between the confluence of East and West Sopris Creek and the Roaring Fork River at Basalt. There are three significant groups of hydrogeologic units at the WSC site: 1) Quaternary and recent unconsolidated materials (predominantly glacial terrace
gravels, colluvium, and modern alluvium) overlying 2) the bedrock unit of the Mancos Shale, and 3) the sandstones and carbonates of the Mancos, Ft. Hays, Dakota/Burro Canyon, and Lower Morrison/Entrada bedrock units (Table 1; Figures 13, 26 and 27).

The Quaternary unconsolidated materials are locally heterogeneous, and consist of clay, silt, sand, gravel, cobbles, and boulders. The average thickness is variable ranging from less than 1 ft to greater than 100 ft. The estimates of hydraulic conductivity range generally between 1 to 100 ft per day (Harlan and Others, 1989). The Mancos Shale underlies most of the unconsolidated units at the WSC site (Figures 26 and 27). This bedrock unit has minimal transmissivity and storage, and is considered a confining unit in the WSC hydrologic system. Note that the terraces identified on the geologic map of the Basalt quadrangle (Streufert and Others, 1998) as Qt1, Qt2, and Qt3 are classified as hydrogeologic unit Qgf (Table 1).

Locally, the sandstone and limestone units in the Mancos; Ft. Hays; Dakota/Burro Canyon; and Lower Morrison/Entrada Formations may serve as minor aquifers in areas where glacial gravels are not adequate for water supply (Kms, Kmf, Kdb, Jme in Table 1 and Figures 26 and 27). The sandstone and limestone units occur as faulted, gently dipping sedimentary beds mainly in the northern area of the West Sopris Creek Valley, and have both matrix and fracture flow characteristics. Given the complex geometry and the complex matrix and fracture flow nature of these hydrogeologic units, these aquifers have variable thicknesses and hydraulic properties based on the geologic materials, geologic structure and respective landscape location.

The Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the location of open areas, irrigation ditch location, and position in the landscape. The unconsolidated units are variably saturated based on spatial location and seasonal precipitation events. There is negligible lateral and upward recharge from the underlying bedrock units into the unconsolidated materials in most locations (Figures 26 and 27). Ground water in the unconsolidated terrace units laterally recharges the unconsolidated terrace units located topographically below by ground water flow through mass wasting units, and the lowest terraces and mass wasting units recharge the modern alluvium by ground water flow (Figures 26 and 27). In addition, ditches located on each terrace or mass wasting unit are influent (losing) and locally recharges the unconsolidated units (Figures 26 and 27). Ground water in the unconsolidated units discharges locally into streams that cut through the terraces, and from the alluvium into West Sopris Creek. Other sources of discharge from the unconsolidated units include phreatophytes and well withdrawals (Figures 26 and 27).

The bedrock system in the WSC area is extremely complex, and needs to be evaluated on a site location basis. Generally, the sandstones and carbonates of the Mancos, Ft. Hays, Dakota/Burro Canyon, Lower Morrison/Entrada, and Maroon and Minturn Formations are located on both sides and underneath the northern part of the West Sopris Creek Valley, and, given the faulted structures, the sandstones have variable dips and continuity (Figures 26 and 27). These sandstones and limestones are recharged by direct infiltration of precipitation, or by ground water moving through the overlying colluvium and unconsolidated materials. Ground water would flow with topography, and would either discharge into the unconsolidated materials of the West Sopris Creek, or could flow up through various fault and fracture zone systems to discharge through the alluvium to West Sopris Creek (Figures 26 and 27). In comparison,
Figure 26. Conceptual Model of the West Sopris Creek Section of the West Sopris Creek (WSC) Subsystem.
groundwater in the northern Sopris Creek/Basalt area may flow from the landslide and alluvial deposits into the bedrock system as shown in Figure 27. Figures 28 and 29 provide a landscape view of the topography, geomorphology and hydrography of the LCR subsystem; Figures 30 and 31 show the Sopris Creek portion of the WSC study area in Pitkin County.

2.6.5 Thompson and Coal Creek (TCC) Subsystem

There are two significant groups of hydrogeologic units in the TCC area: (1) Quaternary unconsolidated materials, which are predominantly colluvial and alluvial deposits, overlying (2)
Figure 28. Google Earth View of the West Sopris Creek Portion of the West Sopris Creek (WSC) Subsystem (looking southwest).

Figure 29. Photograph of the West Sopris Creek Portion of the West Sopris Creek (WSC) Subsystem (panoramic view looking south from West Sopris Creek Road).
Figure 30. Photograph of the Lower Reach of East Sopris Creek.

Figure 31. Photograph of the Area near the Confluence of East and West Sopris Creek.
Pre-Quaternary bedrock units, including the sandstones (coals, carbonates) of the Green River, Wasatch, Mesa Verde, Mancos, Dakota/Burro Canyon, and Lower Morrison/Entrada Formations that may be water-bearing, and the intervening shale that may be poorly transmissive confining layers (Table 1; Figures 13 and 32). The Quaternary unconsolidated materials are locally heterogeneous, with predominantly coarser materials in the colluvium, and finer materials in the alluvial deposits. The thickness of the sediments ranges from less than 1 ft to greater than 100 ft. Estimates of hydraulic conductivity ($K$) ranges from 10 to 100 ft per day (Harlan and Others, 1989). The shale bedrock is the dominant underlying confining layer with small hydraulic conductivity values less than 0.01 ft per day.

Figure 32. Conceptual Model of the Thompson and Coal Creek (TCC) Subsystem Including Jerome Park.
Locally, the sandstone units in the Green River, Wasatch, Mesa Verde, Mancos, Dakota/Burro Canyon, and Lower Morrison/Entrada Formations may serve as aquifers in areas where the colluvium and alluvium are not adequate for water supply (Tgr, Tw, Kmv, Kms, Kd/Kbc, and Jme in Table 1 and Figure 32). These sandstone units occur as tilted/dipping sedimentary beds mainly on the hilltops and hillslopes above Jerome Park, and Thompson and Coal Creeks, and have both matrix and fracture ground water flow. Given the geometry and the complex matrix / fracture flow nature of these hydrogeologic units, these aquifers have variable thicknesses and hydraulic properties based on the geologic materials, geologic structure and respective landscape location. There are some locations where these units are located directly underneath the unconsolidated materials of the Valley, and the unconsolidated and bedrock aquifers may be in direct hydraulic connection (Figure 32). Most wells have not tapped these potential bedrock aquifers in this area.

The Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the slope steepness, slope aspect, and to position in the landscape (Figure 32). The unconsolidated units are variably to fully saturated based on spatial location and seasonal precipitation events. There may be lateral and vertical connection between the sandstones and limestones of the Green River, Wasatch, Mesa Verde, Mancos, Dakota/Burro Canyon, and Lower Morrison/Entrada Formations and the unconsolidated materials in some locations (Figure 32). Bedrock aquifers in the TCC area have a westerly dip; therefore, ground water in these units would tend to be recharged by the overlying unconsolidated materials and Thompson and Coal Creeks and tributaries. Otherwise, the intervening shale does not allow significant lateral or upward/downward movement of ground water from the bedrock aquifers into the unconsolidated materials. The unconsolidated units discharge ground water locally into Thompson and Coal Creeks and tributaries (Figure 32). Therefore, the local ground water flow is from the unconsolidated colluvial materials into unconsolidated alluvium and, finally, to springs, seeps, or to Thompson and Coal Creeks and tributaries. Some of the ground water entering the alluvium may flow parallel to the stream for some distance before discharging to the stream. Additional discharges from the unconsolidated units occur as evapotranspiration and well withdrawal (Figure 32). There may be some reaches of Thompson and Coal Creeks where surface water enters the alluvium to recharge the underlying bedrock system as part of the deep regional recharge zone of the greater Piceance Basin (Figures 12a and 32).

The bedrock system in the TCC area is complex, and needs to be evaluated on a site location basis. The sandstones of the Green River, Wasatch, Mesa Verde, Mancos, Dakota/Burro Canyon, and Lower Morrison/Entrada Formations dip to the west, and are mostly cross cut by Thompson and Coal Creeks and tributaries. These younger sandstones would be recharged by direct infiltration of precipitation, by ground water moving through the overlying colluvium and alluvium, or by losing streams that cross cut the hydrogeologic units. Ground water would flow down dip to the west in these sandstones and become regional flow into the deeper zones of the Piceance Basin beyond the Pitkin County boundaries (Figure 32). Figures 33, 34, 35, 36 and 37 provide a landscape view of the topography, geomorphology and hydrography of the TCC subsystem.
Figure 33. Photograph of the Jerome Park Area of the TCC Subsystem (panoramic view taken near the northern county line).

Figure 34. Google Earth View of the Jerome Park Area of the TCC Subsystem (looking south from northern county line).
Figure 35. Photograph of North Thompson Creek Valley near the Confluence with South/Middle Thompson Creek (looking Southeast with Assignation Ridge in Background).

Figure 36. Google Earth View of the Coal Creek Area of the TCC Subsystem (looking west from Redstone).
2.7 Anthropogenic Influences

Human activity in hill slope and valley bottom subsystems in the study area has affected both the surface and subsurface parts of the hydrologic systems. Past land use and human activity was mostly associated with agricultural production and coal mining and has resulted in removal of native vegetation, introduction of irrigation, construction of (often leaking) irrigation ditches, drilling of mine tunnels and production of mine tailings, and drilling of primarily domestic wells. More recent human activity included the development of residential subdivisions, especially on the colluvium along the Crystal River and on the terraces in the LCR and WSC areas, resulting in changes in ditch water allocation patterns, increased well pumping and ISDS density, reduced pasture and crop irrigation, increased garden watering, increased soil erosion, and modification of vegetative cover and related evapotranspiration.

There are a number of irrigation ditches in the study area, primarily in the LCC and WSC subsystems (Figures 38 and 39). These ditches are mostly unlined, and may have been excavated in mostly unconsolidated Quaternary deposits, weathered shale, or shale bedrock. When carrying water, the ditches may leak, as evidenced by the phreatophytes often found lining the ditch trajectories. The ditch system in the study area contains two types of ditches: 1) primary ditches, which carry water during most of the growing season; and 2) secondary ditches, which carry water only during an actual irrigation cycle. The water leaking from the ditches may be used by vegetation discharging as evapotranspiration, or may recharge the underlying ground water system forming a local ground water mound. As most of the ground water systems in the study area are local in nature, ditch leakage may contribute significantly to the local water balance, increase the water table elevation, and alter ground water flow directions.

The wells in the study area are clustered along the Crystal River and West Sopris Creek, and in the terraces affected by irrigation practices of flood irrigation with transport of water by leaky ditches (Figure 38). As most of these wells serve domestic water supply needs, their individual influence on the ground water system is limited. However, when they are clustered, their accumulated effect on the ground water system may be significant, resulting in a possible lowering of the water table, changes in flow direction, decreasing discharge to streams or increasing stream loss to ground water, draining of wetlands, or even depleting local aquifers.
Other human interaction with the ground water flow system includes recharge from ISDSs, recharge from irrigation return flow (Figures 31 and 40), and recharge from (leaking) irrigation ditches and ponds. Irrigation return flow and leaky irrigation ditches can be a significant recharge element in the local ground water balance. Taking irrigated fields out of production may cause a lowering of the water table and reduction in ground water flow velocities. Leaking ponds and leaking ditches cause mounding of the water table, increased recharge of the local ground water system, and changes in ground water flow direction.

2.8 Summary and Discussion

The hydrogeologic framework of the Crystal River study area has multiple distinct hydrogeologic units, including: 1) Quaternary landslide, hillslope and sheet wash deposits, and colluvium; 2) glacial gravel deposits, terraces and fans; 3) glacial moraines; 4) alluvial deposits; and 5) Tertiary alluvial deposits in the Carbondale Collapse region. The Mt. Sopris granodiorite, and the sandstones and carbonates of the Green River, Wasatch, Mesa Verde, Mancos, Dakota/Burro Canyon, lower Morrison/Entrada, Maroon, Minturn, and Eagle Valley Formation bedrock units are less significant aquifers. West Sopris Creek has a unique set of hydrogeologic units, including: 1) Quaternary landslide, hillslope and sheet wash deposits, and colluvium; 2)
glacial gravel deposits, terraces and fans; 3) glacial moraines; and 4) alluvial deposits. The Upper and Lower Mancos sandstone, Ft. Hays Limestone, Dakota/Burro Canyon, and Lower Morrison/Entrada bedrock units are less significant aquifers. Hydrostructures, which include geologic folds, and fault and fracture zones are observed or hypothesized to transmit ground water either vertically or laterally along dip slopes, fault or fracture planes or zones. These structures may serve as aquifers or connect multiple aquifers together in the CRWS area, or may laterally block local and regional groundwater flow. Prominent examples of significant hydrostructures include the westerly dipping of aquifer units into the Piceance Basin, the Crystal River syncline – Crystal River fault and fracture zone, the Elk Range Thrust in the Upper Crystal River region, the Carbondale Collapse features and resulting formation of the Tertiary sandstone hydrogeologic unit, and multiple folds and fault zones observed at the northern area of West Sopris Creek just south of Basalt, CO., where multiple faults bring the Mancos, Dakota/Burro Canyon, and Lower Morrison/Entrada sandstones to the surface and near surface.

![Figure 39. Photograph of Irrigation Ditch Intake in the LCR area (Sweet Jessup Canal Intake at the Crystal River).](Image)

The general conceptual model of the ground water flow system consists of inputs and outputs based on climate (infiltration of precipitation and snowmelt); stream functions (gaining or losing), springs and seeps; vegetation and wetlands (evapotranspiration); topography
(steepness, aspect, degree of landscape dissection), geomorphology and soils; human activity (irrigation ditches and irrigation, ponds and reservoirs, urbanization, wells and ISDS); and geology. Based on the hierarchical approach of Kolm and Langer (2001), no regional system has been identified as being important, whereas subregional and site-scale ground water flow systems are important in the Crystal River – West Sopris Creek (CRWS) study area.

Figure 40. Google Earth View of Irrigated Areas in the WSC subsystem (looking north).

Based on field work and Hydrologic Systems Analysis, five general conceptual models are identified and discussed within the subregional scale context of the CRWS area: 1) Upper Crystal River (UCR) Subsystem near Redstone, CO; 2) Central Crystal River (CCR) Subsystem; 3) Lower Crystal River (LCR) Subsystem; 4) West Sopris Creek (WSC) Subsystem; and 5) Thompson & Coal Creek (TCC) Subsystem. Each of the five subsystems has a unique set of natural hydrogeologic and hydrologic system parameters. In general, the most important anthropogenic hydrologic system parameters are ground water recharge from irrigation and irrigation ditches, ground water discharge from wells, and ground water recharge from ISDS. If water rights and allocations should change for these ditches, the hydrodynamics of the
Quaternary glacial and alluvial aquifers would change, and water supplies from ground water may decline or vanish. These considerations will be addressed in following chapters integrating the GIS-based analysis and maps with the Hydrologic System Conceptual Model presented in this chapter.